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(54) Abstract Title
Production of moving images for holography

(57) Dynamic images for use in holography are produced by directing light from a source 16 onto a first spatial light modulator (SLM) 18 and relaying the modulated light onto a second, optically addressed SLM 24. The resulting real image from the second SLM may be used in holography. The addressing frame rate of the 1st SLM is substantially greater than that of the 2nd and the system provides an image of greater resolution than previously possible.

The 1st SLM may be an array of liquid crystal modulating arrays or may be a single array (Figures 4 - 6). The image relay may be an array of lenses or a single lens (Figure 3) and may include a shutter array in the embodiments using a single 1st array (Figures 4 - 6).

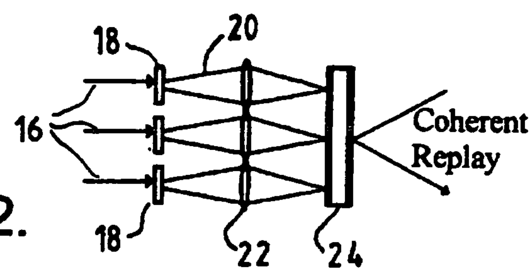

Fig. 2.

GB 2 330 471 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

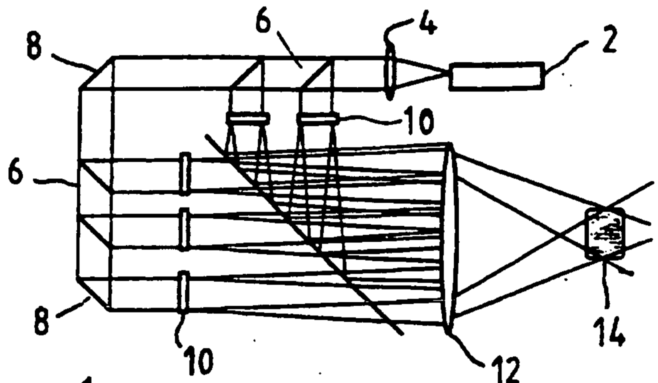

Fig. 1.

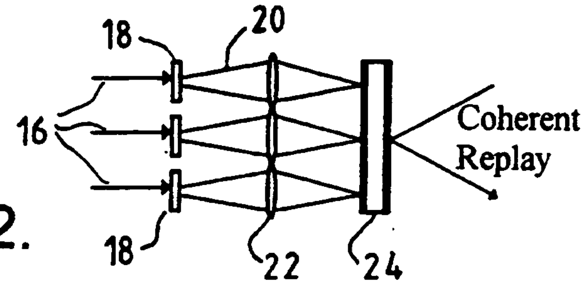

Fig. 2.

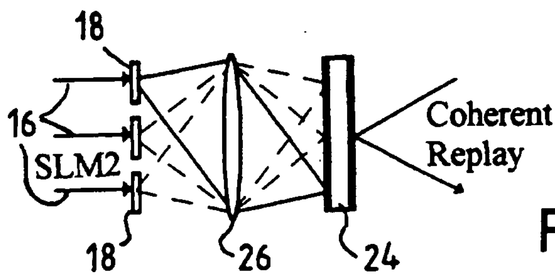

Fig. 3.

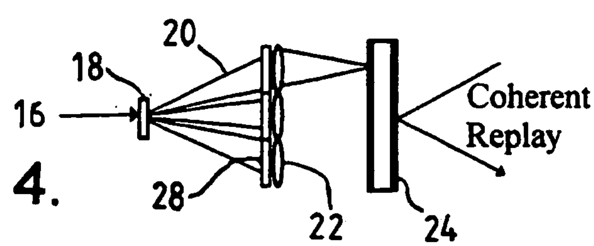

Fig. 4.

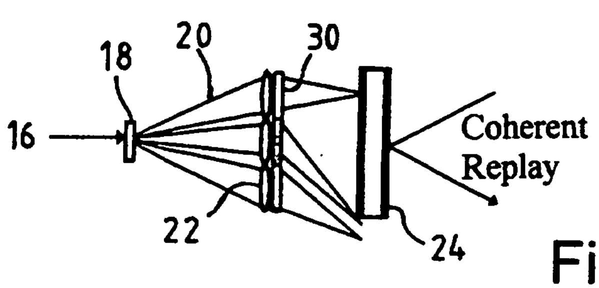

Fig. 5.

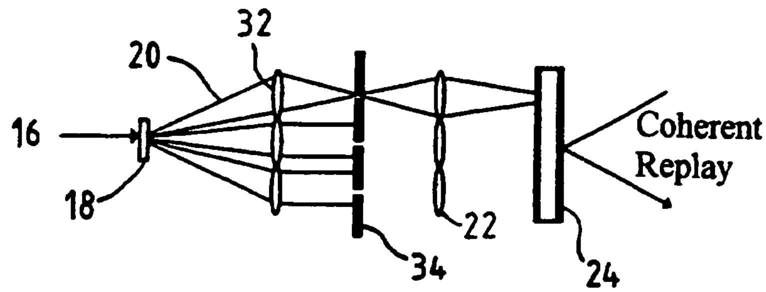

Fig. 6.

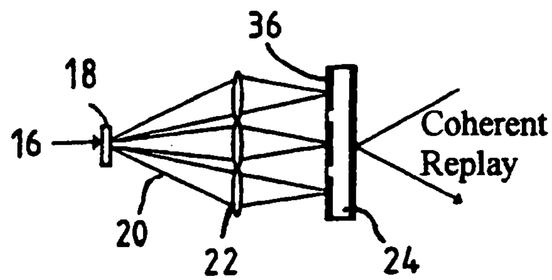

Fig. 7.

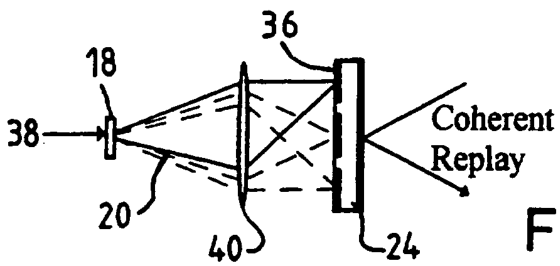

Fig. 8.

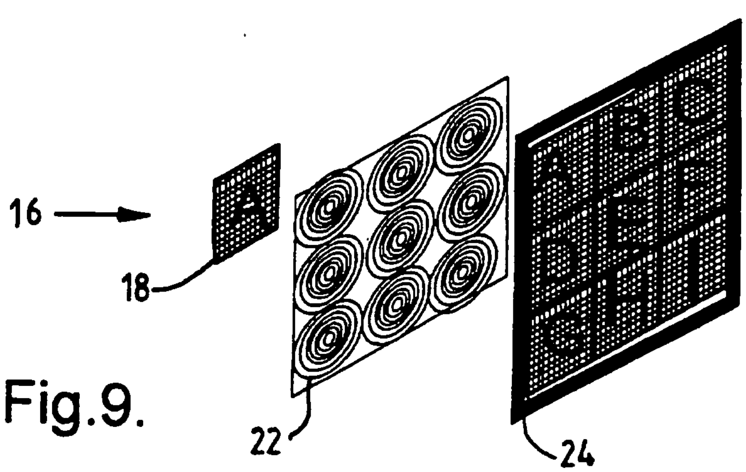

Fig.9.

A SYSTEM FOR THE PRODUCTION OF A DYNAMIC IMAGE FOR USE IN HOLOGRAPHY

The present invention relates to a system for the production of a dynamic image for use in holography and has particular, although not exclusive, relevance to such systems employing liquid crystal display devices.

It has long been known to use holographic techniques to produce a real three-dimensional image of an object which has all of the depth cues used by the human brain in its image processing. Conventionally a real three-dimensional object is used in the production of the hologram by known techniques.

It is also known to use electronic holography techniques which, rather than relay on real three-dimensional object in the production of the hologram, rely upon multiple flat, two-dimensional, object having inherent depth cues encoded as light intensity or phase differences across the surface thereof which can be used to produce a hologram therefrom.

This so-called latent image holography requires high performance photographic emulsions to both record and replay the holograms. In order to achieve the very wide field of view which is desirable for such imaging, it is desirable to have pixel sizes down to around 10 nm. This pixel size also allows for high fidelity and colour to be recorded and faithfully reproduced.

It has been recognised that it would be desirable to produce a dynamic, rather than static object using this two-dimensional object holography technique. This will be possible by simple substitution of the photographic emulsion by some form of electronically addressable spatial light modulator. These may consist of two-

dimensional arrays of electronically addressable light modulation elements, referred to as pixels.

The above desirable result, however, meets with problems because whilst conventional spatial light modulators are fabricated using a wide variety of techniques, they all suffer from an number of problems. None of the conventional spatial light modulators offer the potential to achieve sub-micron pixel sizes which are necessary to achieve the desired field of view. Additionally, none offer the number of pixels typically seen in a latent image hologram. The low resolution due to the low number of pixels results simply from the limits of technology at the present time. Even in leading systems, using a acousto-optic modulators and passive addressed ferroelectric liquid crystal modulators, the maximum number of pixels is limited by various reasons. The acousto-optic systems are limited due to the modulation band width of the acousto-optic modulator which is typically a few MHz. In ferroelectric liquid crystal systems this is due to the manufacturability of very complex displays. Currently 3000x2000 pixels has been achieved.

Accordingly it would be desirable to be able to use an electronically addressable modulator to provide a dynamic image used in holography. The present invention therefore aims to at least alleviate the aforementioned shortcomings.

There is provided, in accordance with the present invention, a system for the production of a dynamic image for use in holography comprising:

a light source; first spatial light modulator means having an associated addressing frame-rate in the path of the light source; relay optics means in the path of the light from the first spatial light modulator means for guiding the modulator light therefrom, and;

second spatial light modulator means having an associated addressing frame-rate in the path of the guided light from the relay optics means and arranged to produce a real image therefrom to be used in holography, wherein the addressing frame-rate of the first spatial light modulator means is

substantially greater than the frame rate of the second spatial light modulator means.

This enable the image produced at the second spatial light modulator means, which operates at a far slower address rate than the first spatial light modulator means, to be effectively governed by the operation of the first spatial light modulator means. This permits a trade off between the temporal information available in high frame-rate spatial light modulators and thereby obtain a high complexity system working at a lower frame rate. It will be apparent to those skilled in the art that the term complexity as used herein refers to the number of pixels forming the grid of the spatial light modulator.

Preferably the second spatial light modulator means comprises an optically addressable spatial light modulator. Use of an optically addressed spatial light modulator enables the active screen formed by the grid of pixels therein to be divided into segments.

Additionally or alternatively the first spatial light modulator means maybe arranged to produce a plurality of modulated light sources from the light source to the relay optics means. In this way the first spatial light modulator may be used to provide a plurality of images for subsequent use within the system.

Additionally or alternatively the first spatial light modulator means may comprise a plurality of spatial light modulators. This allows an alternative way of producing a plurality of images.

The first spatial light modulator means may be electrically addressable. This enables a fast rate of dynamic image to be produced.

Preferably the relay optics means guides modulated light from the first spatial light modulator means to the second spatial light modulator means in a predetermined pattern. Alternatively the relay optics means may modulate the phase or polarisation of

light guided thereby. This permits for predetermined guiding/modulation of light by the relay optics means. The relay optics means may comprise a lens means or an array of individual lenses or a beam splitter or a shadow mask, or holographic optical element.

The complexity of the first spatial light modulator means may be greater than the complexity of the second spatial light modulator means. This allows, for example, for repeat images to be formed on the second spatial light modulator means. In a preferred embodiment, the modulated light from the first spatial light modulator means may be replicated at the second spatial light modulator means by the relay optics means. Additionally the replication of the modulated light may comprise a plurality of images. Usefully the relay optics means guides the replicated modulated light time-sequentially to predetermined portions of the second spatial light modulator. In this way the relay optics means may reproduce an image at the second spatial light modulator of that provided by the first spatial light modulator.

Preferably the second spatial light modulator means comprises a ferroelectric liquid crystal light modulator. Additionally the light source may be an incoherent light source.

According to a second aspect of the present invention there is provided a method of producing a dynamic image for use in holography comprising:

> providing a light source and passing this light source through a first spatial light modulator means having an associated addressing frame-rate; guiding the modulated light via a relay optics means, disposed in the path of the modulated light, to a second spatial light modulator means, which second spatial light modulator means has an associated addressing frame-rate substantially less than the associated addressing frame-rate of the first spatial light modulator; and providing a real image from the second spatial light modulator means.

The present invention will now be described, by way of example only, and with reference to the accompanying drawings of which:

Figure 1 illustrates a known device for the optical recombination of data from a plurality of spatial light modulators;

Figure 2 illustrates schematically a first embodiment of the present invention;

Figure 3 illustrates schematically a second embodiment of the present invention;

Figure 4 illustrates schematically a third embodiment of the present invention;

Figure 5 illustrates schematically a fourth embodiment of the present invention;

Figure 6 illustrates schematically a fifth embodiment of the present invention;

Figure 7 illustrates schematically a sixth embodiment of the present invention;

Figure 8 illustrates schematically a seventh embodiment of the present invention, and;

Figure 9 shows a perspective view illustrative of an eighth embodiment of the present invention.

By referring first to figure 1 a known device for the optical recombination of date from many spatial light modulators is shown. A laser light source 2 provides a collinated beam via lens 4 through a plurality of beam splitters 6 and mirrors 8 to spatial light modulators 10 which then allow the light to pass through a final focusing lens 12 to provide a holographic image 14 in known manner. In order for such a system to be able to replay high complexity high resolution generated holographic images, the light from the spatial light modulators (herein referred to as SLM) 10 needs to be

optically recombined. Those skilled in the art will appreciate that the term "complexity" as used herein refers to the number of pixels in the SLM grid. The example shown in figure 1 utilises the inherent parallel nature of optical systems. Furthermore the complexity available for the generated holographic image atom increases in proportion to the number of SLMs used.

Referring now to figure 2 it can be seen that by utilising an incoherent light source 16 to provide light to be modulated by a series of first spatial light modulator means, in this example electrically addressed liquid crystal (LC) modulators 18, a simpler and less space-consuming arrangement may be employed. The modulated light 20 passing from the liquid crystal modulators 18 next travels via a relay optics means, in this example an array of lenses 22. It can be seen that the array of lenses 22 are convex lenses and serve to focus the modulated light 20 onto a second spatial light modulator means, which in this example is an optically addressed SLM 24. At the right hand side of figure 2 on the right hand surface of the optically addressed SLM 24, is formed a real image which can be used to provide a holographic image in known manner. In the figure this is labelled as "coherent replay" and those skilled in the art will appreciate that this refers to the coherent lazer light impinging upon the real image surface of the optically addressed SLM 24 to produce the holographic image in conventional matter.

The use of demagnifying optics in this example is employed to decrease the effective pitch of each pixel in the SLMs and since the data is projected from several sources i.e. the LC modulators 18, in parallel onto the optically addressed SLM 24 then there is no extra frame-rate requirement on the modulators 18, 24 themselves. In this manner therefore the LC modulators 18 which operate at an addressing frame rate substantially above the addressing frame-rate of the optically addressed SLM 24 may provide a real image on the optically addressed SLM 24 suitable for holography purposes. In this example the LC modulator 18 comprises an active back plane liquid crystal on a silicon device, which has a complexity of 320x240 pixels with a frame-rate

in excess of 1kHz. The optically addressed SLM 24 is an amphorous silicon photosensitive layer which modulates voltages across a reflective liquid crystal layer.

In this example the light source is provided by a computer generated two dimensional phase or amplitude pattern, or it could indeed be an electrically addressed SLM itself. Indeed it would even be possible for the light source to be the LC modulator 18.

Referring now in addition to figure 3 it can be seen that the incoherent light source 16 and LC modulators 18 remain but the lens array 22 has been replaced by another relay optics means, have a single focusing lens 26. Once again, in common with the example of figure 2, the advantage of such a system is that incoherent light is used in the replication of the images from the LC modulator 18 onto the optically addressed LSM 24. This means that the requirements of the optical flatness tolerances of SLMs common in the art, the accuracy to which the SLMs must be oriented on a flat plane and the tolerances on the positions of all the optical components in the projection part of the system, are very much lower than would be the case with the example system of figure 1.

Referring now to figures 4, 5 and 6, it can be seen that examples are given employing a single LC modulator 18 but with alternative forms of relay optics means. In the example of figure 4 the relay optics means comprises a shutter array 28 in the path of the modulated light 20 before reaching the lenses array 22. In these examples the optically addressed SLM 24 is of the ferroelectric type and this allows a high speed application. This is exploited in these example by projecting data from the incoherent light source 16 via the LC modulators 18 and the shutter array 28 and lens array 22 to different parts of the optically addressed SLM 24 in consecutive time frames. The full pattern of the data is thus split up into frames with a number of pixels equal to the complexity of the optically addressed SLM 24. It will be appreciated by those skilled in the art that if the LC modulators 18 have "n" pixels, and the full pattern to be displayed has "m" pixels, then the number of frames of "n" pixels to make up a pattern

of "m" pixels is $\left(\frac{m}{n}\right)$. These frames are displayed time-sequentially on the optically addressed SLM 24 with each frame being projected to a different part of the optically addressed SLM 24 to build up the full image pattern over time. This technique is known to those skilled in the art and is not too dissimilar for example to the Raster scans as used in conventional television display screens. The use of the shutter array 28 is controlled by circuitry to allow the above to take place in known manner. Indeed the lenses of the lens array 22 will each image the modulated light 20 impinging thereon onto a different part of the optically addressed SLM 24. When the pattern is changed via the LC modulator 18 the position of the open shutter of the shutter array 28 is also changed. By cycling through a sequence of different patterns on the LC modulator 18 which are themselves synchronised in time with the opening of different shutter positions in the array 28, a large pattern is build up on the optically addressed SLM 24. The shutters could equally well be replaced by suitable phase plates or switchable polarising plates. If the incoherent light source 16 was arranged to be with linear polarised light and there was a polarising plate between the lens array 22 and the optically addressed SLM 24, then light would be blocked for an element in the phase plate array which was switched to act as a half wave plate. A switchable polariser array could also be used in a similar arrangement, without the need for a second polariser.

In the examples shown in figure 5 the shutter array 28 of figure 4 can be replaced by an array of switchable beam steerers 30. The beam steerer in the examples shown is a switchable diffraction grating of common construction, for example a nematic liquid crystal cell with grating defined in photoresist or in surface relief and which are indexed matched with a liquid crystal in the unswitched orientation but not when it is switched by an electric field. Those skilled in the art will be familiar with this technology so it will not be described any further herein. Alternatively the beam steerers 30 may be of the type including a lenslet array combined and replaced with a switchable or reconfigurable fresnel lenslet array.

switched lens of the array 32 may propagate through the pin hole 34 at its focus and is then re-imaged onto the optically addressed SLM 24 via the lens array 22. For the case of an unswitched lens in the array 32 which allows the modulated light 20 incident therethrough unfocussed, only a small fraction of light will be transmitted through the pin hole array 34. An array of lenses 32 which only acts on one polarisation of light combined with a linear polariser is also possible here.

Referring now to figure 7 it can be seen that, in this embodiment, the optically addressed SLM 24 includes an optical front surface for receiving the light from the lens array 22 via a series of pixellated electrodes 36. In this example the light modulating layer in the optically addressed SLM 24 is arranged to be bi-stable such as ferroelectric liquid crystal display.so that when a voltage is applied to a particular region of the optically addressed SLM 24 a pattern is written into this layer which remains when the voltage is removed. As patterns are displayed time-sequentially on the LC modulator 18, then voltages are applied to active different areas of the optically addressed SLM 24 in synchronisation with this.

Referring now to the example shown in figure 8, the light source here is a coherent light source 38. This example does not require any switchable optical components. The patterns which are displayed time-sequentially on the LC modulater 18 from the coherent light source 38 could themselves be holograms, for example. These are calculated to give the required pattern when projected onto the optically addressed SLM 24. In principle, the optically addressed SLM 24 does not need to have pixellated electrodes 36, however, in practice this may be required to enable the removal of dc components and unwanted diffraction spots.

Figure 9 shows an example of the system of figure 7 but in perspective and not in schematic view. Here it can be seen that it can be light source 16 first travels via the LC modulator 18 and then via the lens array 22 (the shutter array 28 is hidden from view) and finally on to the optically addressed SLM 24. Once again, and in common with all embodiments herein, the image on the LC modulator 18 can be updated at a

relatively rapid rate. The relay optics, here the lens array 22 and shutter array 28 replicate the image formed on the LC modulator 18 onto the input photosensitive face of the optically addressed SLM 24 in an array whose size is determined by the relay optics system. This is because each lens in the array 22 forms a unique image of the LC modulator 18 onto the optically addressed SLM 24. Image magnification can also occur in the relay optics system.

In these examples, because the optically addressed SLM 24 is a bi-stable (such as ferroelectric liquid crystal). Then each segment labelled A to I of figure 9 in the optically addressed SLM 24 sequentially loads the image by applying a voltage to an electrode covering that segment. One or more segments may be loaded in one system clock period. Segments which do not have any voltage applied thereto at that time do not update the image for readout. When the LC modulator 18 updates is image, this can also then be selectively loaded onto the optically addressed SLM 24. In this manner a complex image is built up. When the image has been completed on the optically addressed SLM 24, this can be read out by coherent replay as shown in the figures. It will be appreciated by those skilled in the art that because the addressing frame-rate of the LC modulator 18 is significantly greater than that of the optically addressed SLM 24, then the high frame rate, medium complexity information available on the LC modulator 18 is effectively transferred to the high complexity, medium frame rate of the optically addressed SLM 24.

It will be apparent to those skilled in the art that whilst in the above the relay optics means has been said to guide the light, it could equally well modulate the phase of light incident thereon. Additionally it will be apparent that whilst in some of the above examples a beam steerer has been used, equally a beam splitter may be employed.

CLAIMS:

1. A system for the production of a dynamic image for use in holography comprising:

a light source;

first spatial light modulator means having an associated addressing frame-rate in the path of the light source;

relay optics means in the path of the light from the first spatial light modulator means for guiding the modulated light therefrom, and;

second spatial light modulator means having an associated addressing frame-rate in the path of the guided light from the relay optics means and arranged to produce a real image therefrom to be used in holography,

wherein the addressing frame-rate of the first spatial light modulator means is substantially greater than the addressing frame-rate of the second spatial light modulator means

2. A system according to claim 1 wherein the second spatial light modulator means comprises an optically addressable spatial light modulator.

3. A system according to either one of the preceding claims wherein the first spatial light modulator means is arranged to produce a plurality of modulated light sources from the light source to the relay optics means.

4. A system according to either claim 1 or claim 2 wherein the first spatial light modulator means comprises a plurality of spatial light modulators.

5. A system according to any one of the preceding claims wherein the first spatial light modulator means is electrically addressable.

6. A system according to any one of the preceding claims wherein the relay optics means guides modulated light from the first spatial light modulator means to the second spatial light modulator means in a predetermined pattern.

7. A system according to any one of the preceding claims wherein the relay optics means modulates the phase of light guided thereby.

8. A system according to any one of the preceding claims wherein the relay optics means comprises lens means.

9. A system according to claim 8 wherein the lens means comprises an array of individual lenses.

10. A system according to any of claims 1-7 wherein the relay optics means comprises a beamsplitter.

11. A system according to either of claims 8 or 9 wherein the relay optics means includes a beamsplitter.

12. A system according to any one of the preceding claims wherein the relay optics means includes a shadow-mask.

13. A system according to any one of the preceding claims wherein the modulated light from the first spatial light modulator means is replicated at the second spatial light modulator means by the relay optics means.

14. A system according to claim 13 wherein the replication of the modulated light comprises a plurality of images.

15. A system according to either claim 13 or 14 wherein the relay optics means guides the replicated modulated light time-sequentially to predetermined portions of the second spatial light modulator.

16. A system according to any one of the preceding claims wherein the complexity of the first spatial light modulator means is greater than the complexity of the second spatial light modulator means.

17. A system according to any one of the preceding claims wherein the second spatial light modulator means is a ferroelectric liquid crystal light modulator.

18. A system according to anyone of the preceding claims wherein the light source is an incoherent light source.

19. A system as substantially hereinbefore described and with reference to the accompanying drawings.

20. A hologram (or other diffractive element) or holographic image produced by a system according to any one of the preceding claims.

21. A method of producing a dynamic image for use in holography comprising:

providing a light source and passing this light source through a first spatial light modulator means having an associated addressing frame-rate;

guiding the modulated light via a relay optics means, disposed in the path of the modulated light, to a second spatial light modulator means, which second spatial light modulator means has an associated addressing frame-rate substantially less than the associated addressing frame-rate of the first spatial light modulator; and providing a real image from the second spatial light modulator means.

The Patent Office

14

Application No: GB 9721866.3
Claims searched: 1 & 21

Examiner: Sue Willcox
Date of search: 13 February 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H4F (FCW, FDD)

Int Cl (Ed.6): H04N (5/70, 5/74, 5/89, 9/31)

Other: Online databases: WPI, Japio

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	EP 0517517 A1	(Hughes Aircraft Company) see abstract	
A	WO 94/28457 A1	(Hughes-JVC Technology Corp) see abstract	
A	US 5555035 A	(Mead et al) see Figures 1 and 2 and column 3, lines 18 - 35	

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art.
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